Active Localization of Sound Sources with Binaural Models

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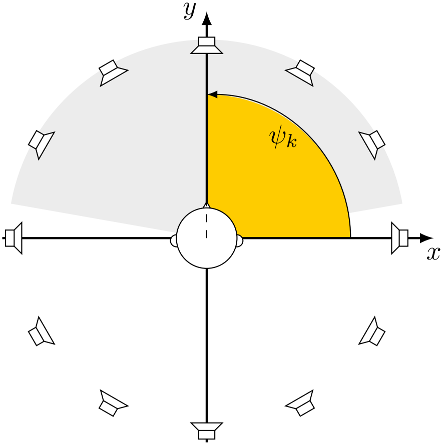
Introduction

Task: Active localization of sound sources in reverberant conditions



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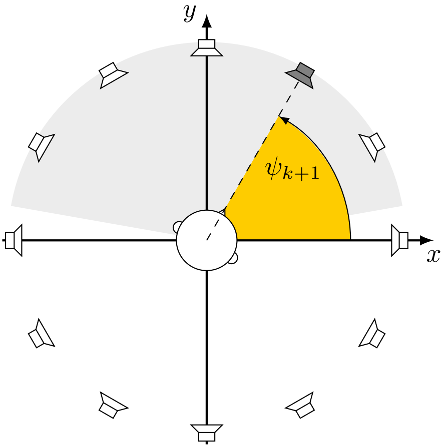

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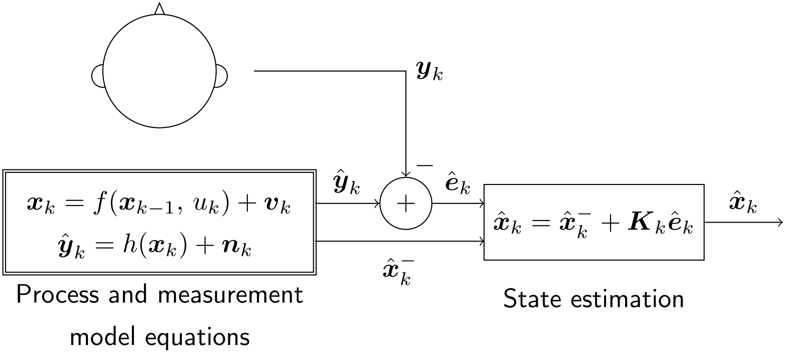
- State-space approach with quasi-continuous head rotations, state estimation and closed loop feedback proposed in [Schymura et al. (2015)].
  - Free-field conditions were considered exclusively
  - Deterministic measurement model (spherical head assumption)
  - Investigation of a single feedback control scheme

System overview



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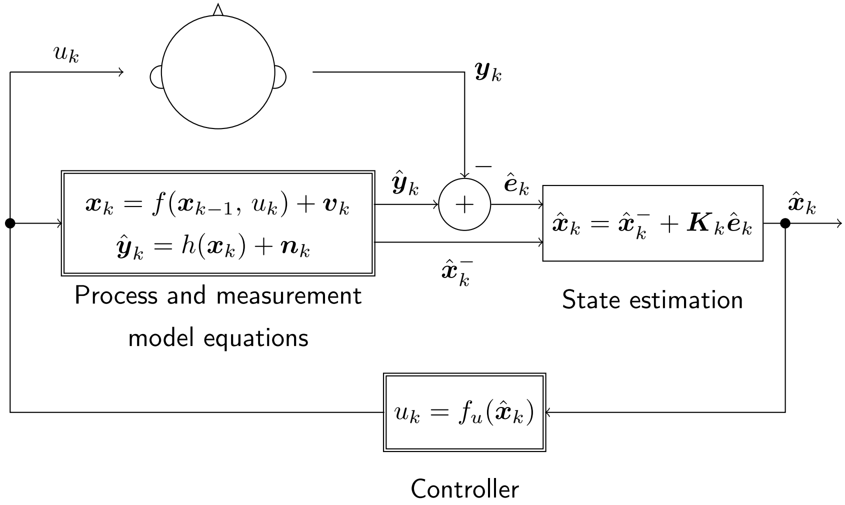

Process model

State space:

$$\boldsymbol{x}_k = \begin{bmatrix} \phi_k & \psi_k \end{bmatrix}^T, \quad \boldsymbol{x}_0 = \begin{bmatrix} 0 & \frac{\pi}{2} \end{bmatrix}^T$$

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System dynamics:

$$f(\boldsymbol{x}_{k-1}, u_k) = \begin{bmatrix} \phi_{k-1} \\ \mathrm{sat}(\psi_{k-1} + T\dot{\psi}_{\max} u_k, \psi_1, \psi_2) \end{bmatrix}$$

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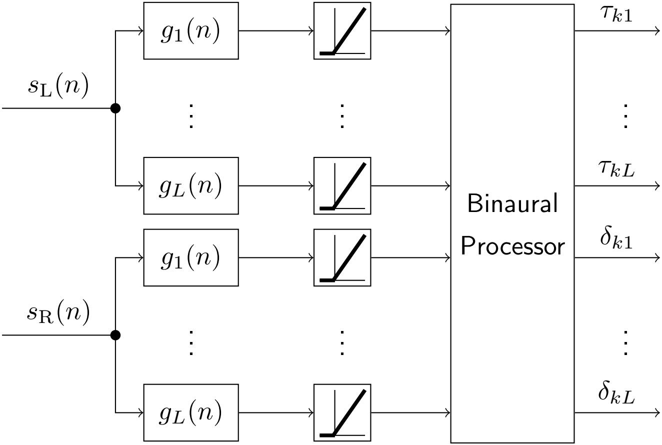
$$\mathrm{sat}(x, \psi_1, \psi_2) = \begin{cases}\psi_1, & \text{if } x < \psi_1 \\ x, & \text{if } \psi_1 < x < \psi_2 \\ \psi_2, & \text{if } x > \psi_2\end{cases}$$

Binaural Front-End



See also: `http://twoears.aipa.tu-berlin.de/doc/1.0/afe/`

Measurement model

Measurement vector:

$$\boldsymbol{y}_k = \begin{bmatrix} \tau_k & \delta_k & \psi_k \end{bmatrix}^T, \quad \tau_k = \sum_{l=1}^{L} \tau_{kl}, \quad \delta_k = \sum_{l=1}^{L} \delta_{kl}$$

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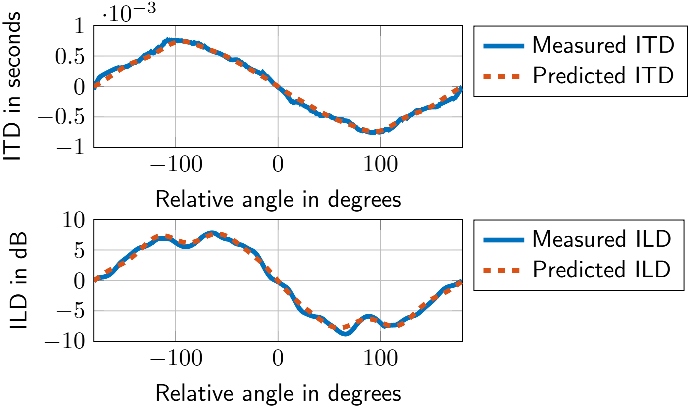
Measurement model:

$$g(\boldsymbol{x}_k) = \begin{bmatrix} w_0^\tau + \sum_{n=1}^{N} w_n^\tau \sin\Big(n \cdot (\phi_k - \psi_k)\Big) \\ \\ w_0^\delta + \sum_{n=1}^{N} w_n^\delta \sin\Big(n \cdot (\phi_k - \psi_k)\Big) \\ \\ \psi_k \end{bmatrix}$$

Measurement model

Training of the measurement model was conducted using anechoic HRTFs of the KEMAR dummy head [Wierstorf et al. (2011)]:



Head rotation strategies

Evaluation of four different approaches:

- No head rotation: $u_k = 0\,\forall k$
- Smooth posterior mean [Schymura et al. (2015)]:

$$u_k = \left(\frac{|\hat{\phi}_k - \hat{\psi}_k|}{1 + |\hat{\phi}_k - \hat{\psi}_k|}\right) \operatorname{sgn}\left(\hat{\phi}_k - \hat{\psi}_k\right)$$

- Proportional controller:

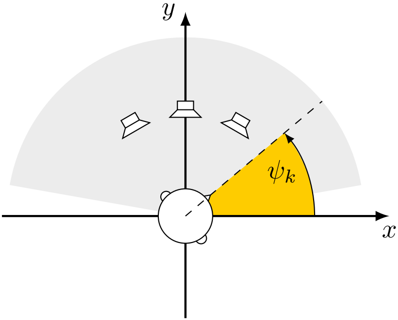
$$u_k = \operatorname{sat}\left(\kappa_{\mathrm{p}}(\hat{\phi}_k - \hat{\psi}_k),\, -1,\, 1\right)$$

- Extended proportional controller:

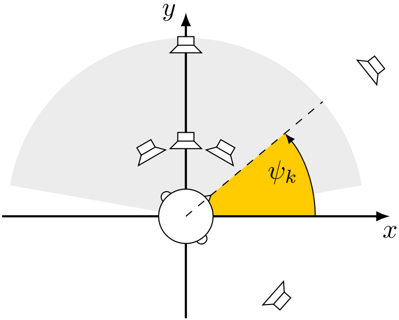
$$u_k = \begin{cases} \operatorname{sat}\left(\frac{\operatorname{tr}(\hat{\boldsymbol{P}}_k)}{\operatorname{tr}(\boldsymbol{P}_0)}(\hat{\phi}_k - \hat{\psi}_k),\, -1,\, 1\right) & \text{if } (k \bmod K_{\mathrm{FB}}) < \frac{K_{\mathrm{FB}}}{2} \\ 0 & \text{otherwise} \end{cases}$$

Evaluation

Evaluation scenarios: Simulated rooms with 3 and 6 fixed source positions, using BRIRs introduced in [Ma et al., (2015)].



Room "Spirit", $T_{60} \approx 0.5\,\mathrm{s}$



Room "Auditorium 3", $T_{60} \approx 0.7\,\mathrm{s}$

Evaluation

Evaluation results: Errors are denoted as circular RMSE in degrees.

	ϕ_S [°]	d_S [m]	NoRot.	SPM	PC	EPC
Auditorium 3	90.00	3.97	**3.38**	7,00	7.04	3.60
	38.49	5.50	42.40	8.60	**8.34**	8.75
	-41.40	2.67	127.71	31.84	30.70	**30.43**
	90.00	1.80	2.67	3.90	3.92	**2.50**
	120.00	1.80	8.85	4.26	4.28	**2.77**
	60.00	1.80	13.30	6.63	6.61	**5.45**
Spirit	120.00	2.00	16.83	17.92	18.84	**8.07**
	90.00	2.00	**4.91**	13.22	13.37	5.15
	60.00	2.00	27.32	20.89	20.87	**12.31**
Average	-	-	27.49	12.70	12.66	**8.78**

Summary

An extension of the binaural model introduced in [Schymura et al., (2015)] was proposed:

- A flexible measurement model using supervised training with individual sets of HRTFs was introduced.
- Two novel head rotation strategies based on proportional control schemes were investigated in reverberant conditions.
- Future extensions of the model may aim at introducing additional degrees of freedom (e.g. translatory movements).

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Thank you for your attention!

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